A STRUCTURAL COMPOSITE MATERIAL FOR ACOUSTIC DAMPING

The present invention relates to a composite material for acoustic and mechanical damping and methods for its production. In particular, the present invention relates to such material having advantageous static and dynamic characteristics. That is, the material should be strong and stiff enough to be formed into structural components and to bear a static load, while being capable of effectively absorbing acoustic and/or mechanical vibrations. It should also be rigid enough in order to restrict flexural deformations when the structure is loaded.

The composite materials in question typically have a layered structure. One common example comprises layers of glass fibre matting or non-crimped fabric embedded within an epoxy resin. Such material has a high static strength, but a poor dynamic performance. That is, such material is structurally strong, but has very poor acoustic or mechanical wave damping characteristics.

In many situations, it is required to provide a material which is structurally strong and stiff, provides efficient damping of acoustic and/or mechanical vibrations but is lightweight. For certain applications, it is desirable that such material should also be non-magnetic and capable of meeting fire and flame spread standard tests such as UL 94V0.

A material known to have good static and dynamic properties is a metal-rubber-metal sandwich structure. Typically, the relative thicknesses of the layers are 4:1:1. The thickness of the rubber layer should be at least half the wavelength of the lowest frequency which is required to be damped. Such material does not provide the characteristics required of the present invention. It is not lightweight, the metal is typically steel for cost considerations and so is typically magnetic, and the structure is liable to delamination at the interfaces of the metal and rubber layers. Similar structures using other materials such as resin impregnated fibreglass matting panels separated by a layer of high hysteretic loss, such as rubber, are described in documents such as United States patent 5,368,916 and United States patent 5,446,250.

Such a structure has only the structural strength of its main panel. For example, a panel having relative thicknesses of the layers 4:1:1 and an overall thickness of 6mm will have a structural strength approximately equal to that of the 4mm layer alone. Any attempt to impose a structural load on the other two layers will lead to damage and delamination of the panel.

The present invention accordingly provides a stiff, lightweight material with effective damping properties for acoustic and/or mechanical vibrations, which is resistant to delaminations and is non-magnetic if necessary. Such material is preferably also available at low cost. Such material preferably also provides improved structural strength without significant increase in thickness.

More particularly, the present invention provides a composite material for acoustic or mechanical damping, comprising: a plurality of layers of fibrous material embedded in a structural matrix material. A layer of high hysteretic loss material is provided between consecutive layers of fibrous material, said layer of high hysteretic loss film being bonded to the adjacent layers of fibrous material embedded in the structural matrix material. The layer of high hysteretic loss material is perforated, so that the structural matrix material is continuous through the perforations between the adjacent layers of fibrous material embedded in the structural matrix material. The perforations may occupy 5-50% of the area of the layer of high hysteretic loss material.

As a result of the layer of high hysteretic loss material being perforated, so that the structural matrix material is continuous through the perforations between the adjacent layers of fibrous material embedded in the structural matrix material, the structural strength of the resulting material will be practically equal to that of a continuous layer of a composite material comprising the fibrous material in the structural matrix material, equal in thickness to the whole thickness of the material in question. For example, a panel of the material of the invention, having relative thicknesses of the layers 4:1:1 and an overall thickness of 6mm will have a structural strength approximately equal to that of a 6mm layer of the fibrous material in the structural matrix material. According to the present invention, a structural load may be imposed on all of the layers without risk of damage and delamination of the panel. The damping and other required characteristics of the material of the invention remain good.

In an embodiment of the invention, the structural matrix material comprises an epoxy, polyester, or phenolic resin; the high hysteretic loss material comprises polyurethane film; and the fibrous material is glass fibre matting.

The present invention also provides a method for producing a composite material for acoustic or mechanical damping. The method comprises the steps of: providing at least one first, fibrous, layer impregnated with a first structural matrix material; stacking the at least one first, fibrous, layer on a former; providing at least one second layer comprising a material of high hysteretic loss; stacking the at least one second layer on the stack of the first, fibrous, layer(s); providing at least one third, fibrous, layer impregnated with a second structural matrix material; stacking the at least one third layer on the stack of first and second layers; and simultaneously heating and compressing the resulting stack of first, second and third layers to cause the material of the second layer(s) to bond with both the first and third layers. The method further comprises the step of perforating the second layer(s) prior to the step of stacking the second layer(s), whereby the structural matrix material (14) is continuous through the perforations (34) between the adjacent layers of fibrous material (12) embedded in the structural matrix material. The step of perforating may comprise forming perforations which occupy 5-50% of the area of the second layer(s).

The method may further comprise the step of selecting the direction of the fibres and fibre types in the fibrous layers to provide a desired combination of structural strength, stiffness and damping properties.

The second layer may comprise a film of viscoelastic polymer film material.

The step of compressing may be performed by enclosing the stack in a heat-shrinking material prior to the heating step. The heat shrinking material may be polyamide tape.

The first and/or second structural matrix material may each comprise an epoxy, polyester or phenolic resin;. or a polyurethane. The high hysteretic loss material may comprise polyurethane. The fibrous layers may comprise glass fibre matting.

In an embodiment having a thermosetting material as a structural matrix material, the step of heating and compressing may preferably be effective to harden the thermosetting material.

A pure epoxy/glass or metal layer may be placed on one surface of the composite material.

The heating and compressing step is effective to cause good bonding and interfacial strengths between the layers. By increasing the temperature it is also possible to diffuse or intermingle the material of high hysteretic loss, typically comprising a thermoplastic film polymer, into the structural matrix material, thereby increasing the strength of the resulting structure and reducing the abruptness of the junctions between first and second layers and second and third layers.

The first and/or second structural matrix material may comprise an epoxy or polyester resin. The second layer may comprise polyurethane or other polymer film. The fibrous layers may comprise glass fibre matting or non-crimped fabric. For applications where electrical insulation is not required it is possible to stiffen the material by replacing the whole or part of the glass reinforcement with a higher stiffness fibre such as carbon or aramid.

The above, and further, objects, characteristics and features of the present invention will become more apparent from consideration of the following description of certain embodiments thereof, in conjunction with the accompanying drawings, wherein

Figs. 1-3 show partially cross-sectional views of materials according to embodiments of the present invention;

Figs. 4-7 show woven fibrous layers suitable for inclusion in the material of the present invention;

Fig. 8 shows, in cut-away plan view, several non-crimped fibrous layers of an embodiment of the present invention; and

Fig. 9 shows comparative test results of a sample of the material of the present invention compared to a sample of conventional material.

Fig. 1 shows a material 10 according to an embodiment of the invention. The embodiment shown in Fig. 1 mimics the 4:1:1 relative thickness ratio known from the prior art metal:rubber:metal structures. The material comprises a number of fibrous layers 12. The illustrations of Figs 1-3 are expanded in thickness for ease of understanding. In reality, the fibrous layers 12 will be more closely packed than shown in the drawings. Each of the fibrous layers may comprise a woven or non-crimped fibrous material, such as a glass fibre cloth, or carbon fibre matting, KEVLAR (TM) or steel mesh, or any other structurally strong fibrous material. Such materials are selected according to the intended final application. The fibrous layers are embedded within respective layers of a structural matrix material 14.

The structural matrix material 14 may comprise a structural composite resin. Examples of structural composite resin include epoxy, polyester, vinyl ester, phenolic and polyurethane resins.

A material of high hysteretic loss is provided at an intermediate layer 24. Examples of the material of high hysteretic loss material include polyurethane, polyesters, polyethylene and other polymer matrices. This material will hereafter be referred to as a "lossy material", for brevity.

The inventors have found that epoxy resin is an inexpensive but effective structural matrix material 14. The inventors have also found that polyurethane is an inexpensive yet effective lossy material 24. The inventors have also found that glass fibre non-crimped cloth is an inexpensive but effective material for the fibrous layers 12. These materials will be referred to throughout the present description. However, such references are not to be construed as limiting, and other materials such as those listed above, may be used provided that they have the required properties.

The composite material of the present invention has acoustic or mechanical damping properties. It comprises a plurality of layers of fibrous material 12 embedded in a structural matrix material 14. Preferably, the structural matrix material comprises a composite including a matrix resin, which can be any suitable thermosetting laminating resin based on epoxies, phenolics, polyesters, vinyl esters; or other materials such as polyurethane. The reinforcing fibres can be glass, carbon or polymer based. The damping properties are provided, according to an aspect of the present invention, by laminating films 24 of a lossy material, such as a thermoplastic material, between layers of the structural matrix material 14. This thermoplastic material may be based on polyether based polyurethanes, polyester based polyurethanes, polyethylene, PVC or copolymers, for example. The film 24 is typically 50 - 400μm thick.

For high strength products good bonding between the lossy material 24 and the structural matrix material 14 is promoted by ensuring the absence of internal release agents during processing of the material of layer 24 and / or by the use of corona treatment applied to the sheet surfaces.

According to the present invention, perforations 34 are provided in the lossy material of layer 24. During compression of the material, prior to the hardening of the structural matrix materials 14 of layers 26, 28, the perforations 34 fill with structural matrix material 14 from layers 26, 28, providing a continuous artefact of structural matrix material 14. The perforations 34 may be of any suitable size or shape. For example, they may be square, circular, elongate, triangular or hexagonal. They may be regularly or irregularly spaced. Where the interlaminar shear strength has to be maximised, the perforation of the lossy material layer 24 with a regular pattern of 5-50 area percent of holes can be provided without compromising the enhanced damping characteristics. Indeed at some frequencies the damping is further enhanced by the inclusion of such perforations.

By using perforations in the lossy material layer a continuous interlayer interface is avoided. This 'fuzzy' interface avoids the problem of low laminate shear strength, whereby known laminates including a damping layer were liable to delaminate due to the high shear stresses occurring at the interface between the structural layers and the damping layer. According to the present invention, high flexural strengths and stiffnesses are retained whilst at the same time, excellent acoustic damping characteristics are maintained. Indeed, enhanced shear strain at the boundaries of the perforations 34 which during processing are filled with structural matrix material acts as to increase the damping at certain frequencies.

In use, the structural matrix material 14 provides high structural strength and stiffness. The high damping is a result of hysteretic loss in the lossy material of layer 24. The material 10 of the invention may be used for soundproof cladding, in which the material need only be self-supporting, or may be structural in the sense of bearing a significant static applied load. The majority of the applied static load will be borne by the thicker layer 26 of the structural matrix material 14. The structural matrix material 14 and fibrous material 12 should be chosen and dimensioned according to the required mechanical strength. The perforated lossy material 24 functions as an absorber of acoustic or mechanical vibrations. Upper layer 28 provides a hard outer surface, allows the intermediate layer 24 to function, as will be described below, and may act as a receiver of the vibrations to be damped. Upper and/or lower surfaces 20, 22 may be provided with a decorative layer integral to the material 10.

When an acoustic or mechanical vibration is applied to the solid upper layer 28, such layer transmits the vibrations though to the lossy layer 24. The upper layer 28 will flex to some extent under the influence of the vibrations. Such flexing will cause tension within the fibres of the fibrous material 12. The fibrous material will disperse the stresses in layer 28 caused by the acoustic or mechanical vibration over a larger area of the upper layer 28, than would be the case in the absence of the fibrous material, or through an area of choice through careful fibre lay-up design. The upper layer 28 conveys the vibration of this larger, or chosen, area of upper layer 28 to a correspondingly sized portion of the lossy layer 24. Thus, the fibrous layers 12 function to spread the applied vibrations over a larger, or chosen, area of layers 28 and 24. This is in addition to their well-known properties of adding structural stiffness and strength. The lossy layer 24 comprises materials with a relatively high hysteretic loss. Such materials will absorb a large proportion of the applied vibration, converting it into a small amount of heat. Very little of the originally applied vibration will reach the lower layer 26, and the material has accordingly performed its intended function of damping the applied vibrations. Similarly, acoustic or mechanical vibrations applied to the lower layer 26 will be damped by layer 24, and very little of the applied vibration will reach the upper layer 28.

The characteristic path length (thickness) of lossy layer 24 should be at least equal to one-half of the wavelength of the lowest frequency vibration which it is intended to damp. Typically, the material of the present invention may be made to effectively damp acoustic waves of 200Hz and above, while having a path length (thickness) in the range of 4-12mm.

The particular composition and dimensions described with reference to Fig. 1 are only one example of the type of materials provided by the present invention. Further examples are described below.

An example of a method for producing the material of Fig. 1 will now be described. A former is first provided. This may be in the form of a flat surface, or may be in the form of a contoured article to be produced in the material of the invention. A first layer of fibrous material 12 is impregnated with a chosen structural matrix material 14, such as an epoxy resin, and the layer is applied to the former. Where high drape is required the fibrous material 12 is chosen with good drape characteristics. Chopped strand mat, non-woven felt or ±45° non-crimped fabric petals have been found to be effective. Further such layers may be stacked onto the first such layer. At least one layer of high hysteretic loss film material 24, such as polyurethane, is laid onto the first layer(s). The lossy layer 24 is perforated 34, as illustrated in Fig. 1. Further such layers may be applied, separated by at least one further layer of fibrous material 12 impregnated with structural matrix material 14. Finally, at least one further layer of fibrous material 12 is impregnated with a structural matrix material 14, such as an epoxy resin, and is laid over the stack of layers described. The resulting assembly will be a "sandwich" structure, having at least one perforated layer of high hysteretic loss film material 24, such as polyurethane, enclosed between layers 26, 28 of fibrous material 12 impregnated with structural matrix material, such as an epoxy resin. The materials used as the structural matrix material of layers 26 and 28 may be different from each other, or may be the same.

The resulting assembly is then compressed and heated, according to techniques known in themselves, to cure the structural matrix materials 14, such as epoxy resin. The lossy material 24 may be either left intact during this operation if temperatures less than the film material's melting point are used in processing; alternatively the film 24 may be partially melted and partially dispersed into the more rigid structural matrix materials 14, if the heating step reaches a sufficiently high temperature. The structure can be further heated to post cure the structural matrix materials, if required.

The resulting structure is then allowed to cool and is removed from the former. Decorative layers may be applied as the first and/or last layers in the stack of fibrous layers. The compressing step may be performed by any suitable method, such as by application of a press, or an inflatable cuff, or by vacuum bagging, or by closing a mould tool.

The compressing step may be performed by applying an upper former to the assembly of fibrous layers and applying pressure. The former(s) may each have a decorative pattern 20, 22 applied which may be transferred to the structure of the material of the present invention. The compressing step may alternatively be performed by enclosing the stack of layers within a further layer of a material which is relatively inert, but which shrinks at the temperatures required for curing. The inventors have found that a polyamide cloth tape is suitable for this purpose. A vacuum may be applied to an outer polymer film to consolidate the component through its thickness.

An increased applied pressure will tend to enhance the bonding between the structural resin (e.g. epoxy) and the high hysteretic loss film material (e.g. polyurethane) and also increase the fibre volume fraction in the composite.

Fig. 2 shows material 401 according to a further embodiment of the present invention. The material 401 differs from the material 10 of Fig. 1 in that the lossy layer 24 is placed substantially centrally within the structure and that layer has an increased thickness as compared to the corresponding layer in material 10 of Fig. 1. This embodiment demonstrates that the relative position and thickness of the layers 26, 28 may be varied at will, in order to achieve a desired set of static and dynamic characteristics. The material of Fig. 2 may be expected to have similar, or somewhat lower static (structural) strength than the material of Fig. 1, but to provide a more effective dynamic characteristic, that is, to be more effective at damping acoustic and mechanical vibrations.

Fig. 3 shows a material 601 according to a further embodiment of the present invention. The material of Fig 3 differs from the materials of previous embodiments principally in that a plurality of layers 24 of lossy material are provided. Such plurality of layers are separated by separating layers 30 comprising fibrous material 12 and an epoxy resin, or other structural matrix material 14, as for lower and upper layers 26, 28. Such material 601 may be produced by a method similar to that described for the material of Fig 1 and 2, but in which one or more layers of impregnated fibrous material 12 is placed between lossy layers 24.

The material of Fig 3 may be expected to have a significantly improved dynamic (vibration-damping) characteristic as compared to a similar material having a single lossy layer 24 of thickness equal to the sum of the thicknesses of the lossy layers 24 of Fig. 3.

As illustrated in Fig. 3, the perforations 34 in the various layers 30 may be of differing sizes, spacing, shapes and orientations. One may select the characteristics of the perforations in each layer to provide a desired damping performance. The perforations 34 may be irregularly spaced in any layer 24, again to provide a desired damping performance.

As described earlier, one of the functions of the fibrous layers 12 is to disperse the applied vibrations over an increased surface area of the layer 26, 28, 30 receiving the vibrations. This occurs by the vibrations causing flexing of the structural matrix material, which in turn causes tension in the fibres of the fibrous material 12, which causes tension in regions of the fibrous layers distant from the original point of application of the vibration. This causes the applied vibration to be spread over a wider area of the lossy layer 24, increasing the overall damping efficiency. This function of spreading the tension can only occur in the direction of the fibres of the fibrous material 12.

Fig. 4 shows a typical fibrous material suitable for use as the fibrous material 12 in the material according to the invention. A fibrous material, for example, glass fibre cloth, is woven or stitched in separate non-crimped layers with strands at 0° and 90° to the direction of feed of the material as it is applied. Use of this material will allow stresses applied at a certain point to be dispersed at angles of 0° and 90° from the point of impact.

Similarly, Fig. 5 shows another fibrous material suitable for use as the fibrous layers in the material according to the invention. This fibrous material, for example, glass fibre cloth, is woven with strands at 45° and 135° to the direction of feed of the material as it is applied. Use of this material will allow stresses applied at a certain point to be dispersed at angles of 45° and 135° from the point of impact.

Similarly, Fig. 6 shows another fibrous material suitable for use as the fibrous layers in the material according to the invention. The fibrous material, for example, glass fibre cloth, is woven with strands at 30° and 120° to the direction of feed of the material as it is applied. Use of this material will allow stresses applied at a certain point to be disposed at angles of 30° and 120° from the point of impact.

According to an aspect of the present invention, use of a certain combination of such materials as the various fibrous layers 12 of the material of the invention allows applied stresses to be spread from the point of application in multiple directions, increasing the efficiency of spreading, and correspondingly increasing the effectiveness of the material's vibration damping properties.

According to the desired application, a product produced in the material of the invention may have preferred directions in which stresses could be applied. Stresses could be preferentially directed in those directions by carefully selecting and/or aligning the fibrous material used in the fibrous layers, for example, those shown in Figs. 4-6. For materials subjected to hydrostatic pressure a quasi-isotropic lay-up through each point of the component thickness is most appropriate.

Fig. 7 shows a further fibrous material suitable for use as the fibrous layer of the material of the invention. In this material, which may alternatively be orientated similarly to that shown in Figs 5-6, or otherwise, one direction of the weave has a significantly greater density of fibres than the other direction. Since tension is transmitted within the layers of the material of the invention along the fibres of the fibrous material, the use of the fibrous material of Fig. 7 will preferentially transmit stresses in the direction of the higher density of fibres. By appropriately selecting and aligning such a fibrous material as one or more of the fibrous layers within the material of the invention, stresses caused by applied acoustic or mechanical vibrations may be preferentially dispersed in selected directions. The requirement for such functionality will be determined by the required characteristics of the article being produced from the material of the present invention.

Fig. 8 illustrates, in cut-away, the fibrous materials of various layers of a sample of material according to the present invention. As can be seen, fibrous material according to each of Figs. 4-7 has been included, as respective fibrous layers 12 within the material. This will provide a particular, and relatively complex, pattern of dispersion of applied stress. It would be unusual to require such a number of different fibrous materials within one sample of the inventive material, and a maximum of two or three different types of material or orientation would be typical.

Fig. 9 shows results of tests performed on a sample of the material of the present invention. Vibrations varying in frequency from 0Hz to 2557Hz were applied to a sample of the material according to the invention, and a sample of conventional GRP, that is, epoxy resin containing glass fibre matting. Curve 50 shows the amplitude of vibration of the sample of conventional GRP over the range of applied frequencies, while curve 60 shows the corresponding amplitude of vibration of the sample of material of the invention over the same range of frequencies. As can be seen, the material of the present invention provides very effective damping of vibration at audio frequencies. At frequencies below about 220Hz, the tested sample of the material of the invention is not effective at damping. This is because the damping layers 24 of the sample had a thickness less than half a wavelength of frequencies of 220Hz and below. This could be cured, if necessary for the intended application of the material, by increasing the thickness of the damping layer 24.

The invention accordingly provides an inexpensive, rigid, lightweight damping material which is resistant to delamination and may also be non-magnetic.

Although certain specific materials have been disclosed, these are not limiting and many other materials may be used, depending on cost, the required mechanical characteristics and the required application of the resultant material. The fibrous layer 12 may be composed of conductive material such as carbon fibre or steel mesh, for example to provide RF screening. The fibrous layers 12 may be composed of respectively different materials, or a fibrous material comprising elements of different materials, such as glass fibre, carbon fibre, polymer fibre, aramid, copper, steel, may be specially produced and used for particular applications.

The material provided by the present invention finds many industrial applications. For example, automotive dashboards made from the inventive material would reduce noise transmission and would be less likely to rattle. Automotive body parts and other items, such as rudders for boats, may be made from the material of the invention to provide a "luxury" feel, without adding to weight. The mechanical and acoustic damping properties of the material of the invention will mean that such parts do not easily resonate, and behave much as a heavy metal component of much greater mass would behave. Turbine blades could be constructed from the material of the invention. The properties of the material may be varied by using different combinations and compositions of layers, for example to provide very effective damping at the tips of turbine blades, to prevent mechanical resonance, combined with high structural strength toward the centre of the turbine blade to provide a strong mounting point. Dampers may be made from the material of the invention, for example, to prevent oscillation of structural steel wires under tension.

Further possible applications include lightweight transmission shafts for vehicles, MRI (magnetic resonance imaging) magnet gradient housing; MRI magnet gradient coil vacuum housing; aircraft engine cowl; aircraft engine supporting structure; airframe parts, primary or secondary; control of flutter in flying surfaces; housing for other equipment, e.g., road drill mining/construction equipment; damping oscillation in automatic systems; changing the load response and geometry response of structures to optimise stress and deflection in design of structures to meet static and or dynamic requirements; improved performance in powder delivery systems; reduction of vehicle noise in motor cars, trains, aeroplanes etc.

The invention accordingly provides a composite construct which can be tuned to deliver the desired blend of structural and dynamic properties, to control or reduce vibration, in terms of amplitude of vibration and the number of dominant frequencies of vibration, in a structure covering or mounting a source of vibration. Particular static and/or dynamic stress requirements in the design of housings or structures may be met by changing the load response and geometry response of structures, according to certain aspects of the invention. The material of the invention may be adapted to have a low strength but a high damping for use in no- or low-stress applications.

Alternatively, the material of the invention may be adapted to have very high structural strength, but with damping characteristics much improved over known materials. The overall level of noise and vibration emitted from a structure of the present invention may be reduced to 10%-20% that emitted from a similar structure of conventional materials such as epoxy resin and glass fibre alone. In a specific example, a composite of fibreglass 12 with epoxy resin 14 has perforated thermoplastic polyurethane film layers 24 dispersed between each layer of epoxy resin and glass fibre, such that the structural properties exceed those available in materials exhibiting a similar level of damping, while also exhibiting damping properties which exceed those available in materials exhibiting similar mechanical strength. By a process of placing and adjusting the level and thickness of the film, and the size, shape and position of its perforations, the amplitude of noise and vibration can be reduced and the total number of dominant frequencies in a band of frequencies can be reduced to "tune" a structure. In the same way, it is also possible to simultaneously achieve mechanical strength required to design a thin walled vessel for use in, for example, MRI (magneto-resonance imaging) equipment. Such level of combined strength and damping has not previously been observed in the prior art.

The optional provision of pure epoxy/glass fibre or metal layer on one surface of the material may prevent outgassing into a vacuum. Similarly, such still layers may be advantageously applied to highly loaded extreme fibres of the material of the invention.

The mechanical strength of the material may also be increased by increasing the density of the fibrous material 12, either by providing more layers of fibrous material per unit depth, or by providing fibrous material of a denser weave.